Laurent Vanbever
My research goal? **Automate, 1 network at the time.**

“SDN” with a twist

Currently
Assistant prof. @ETHZ

Before
Post-doc @Princeton U

Before
PhD @UCL Belgium
Develop a complete & sound network controller which can automatically enforces high-level requirements

Network controller

- Analyze
- Plan
- Execute

- Monitor
- control algorithms
- visibility
- Programmability

- Adaptative Networked System
Introduction Slides

Alexander von Gernler
<gernler@genua.de>

Munich Internet Research Retreat
Raitenhaslach, November 24, 2016
Alexander von Gernler

- Head of Research at genua GmbH
  - Post Quantum Crypto, FPGA Packet Filters, Advanced Persistent Threats, Software Defined Networking, Security in Critical Infrastructures, Micro- and Separation Kernels, ...

- GI Junior Fellow
  1. Networking between OpenSource and Academia Communities
  2. Effort for more efficient Funding of Research
  3. IT Security and Privacy post-Snowden

- OpenSource Hobbyist
  - OpenBSD-Committer 2005-2010
  - `$ ssh -o 'VisualHostKey yes'. Did it.`
About genua

- IT security company
  - founded in 1992
  - Kirchheim bei München
  - 240 employees (October 2016)
  - part of Bundesdruckerei group since August 2015

- Firewalls, VPN-Gateways, Fernwartung
  - packet filters, application level gateways
  - OpenBSD-based
  - certified by German BSI: Common Criteria, EAL4+

- Reference Customers
  - MAN, RTL II, Hypo-Vereinsbank, Klüber, …
  - BSI, Generalbundesanwalt, Stadt München, Bundeswehr, …
TUM LKN: Arsany Basta

Next Generation Mobile Core Network based on SDN, NFV and NV

- **Motivation**
  - Current mobile core network built out of dedicated hardware
  - Inflexible and induces high cost to setup and maintain
  - investigate concepts of SDN, NFV and NV at the mobile core

- **Approach**
  - design and model the resources dimensioning of the mobile core, based on SDN and NFV [1-2]
  - develop SDN virtualization solutions to provide flexible, resilable and dynamic slices towards 5G [3-4]

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Arsany Basta, LKN, TUM 2016  arsany.basta@tum.de
Next Generation Mobile Core Network based on SDN, NFV and NV

- **Research Questions**
  - resource optimization, i.e., controllers, data centers, vms, ..?
  - measurements and observations of NFV and SDN prototypes?
  - solutions for reliable SDN virtualization layer?
  - SDN virtualization layer to cope with network dynamics?

- check out “HyperFlex ”SDN virtualization Poster
  - HyperFlex design goals
  - HyperFlex features
  - HyperFlex demos
  - HyperFlex open questions

Arsany Basta, LKN, TUM 2016 arsany.basta@tum.de
About myself

Professional Background

• Director of Future Network Technologies at Huawei ERC, Munich.
• Associate Professor and Network Security research leader at the Computer Science and Networking Department of Telecom ParisTech, France.
• PhD in network security (ENST, Paris), Dipl.inform. (University of Karlsruhe).

Current Research Interests

• 5G Mobile Core Network
• Programmable network infrastructures
  • Not “Network as a Service”, rather “Network infrastructure as a Cloud”
• Support of critical services in software networks
• Resilience of software networks
Open Questions

● How to support critical and massive MTC in 5G?
  □ Critical => reservations => state \textit{vs.} massive => scalable => no state

● Multi-domain operations with software networks
  □ Let Network \textit{a} have behavior \textit{A} and Network \textit{b} – behavior \textit{B}. Roaming from \textit{a} to \textit{b}???

● Software Network Management
  □ How can one design a scalable management system for a software network, the behavior of which is not clear at the moment of its deployment?

● Software Network Control Problem
  □ How can one design a resilient network control system for a software network without severely limiting its programmability?
My Research Interests

Claas Lorenz
<claas.lorenz@genua.de>

- IT-Security Researcher with genua
- Currently working on SDN/NFV-Security in the BMBF project SarDiNe
- Research Interests:
  - Firewalling in General
  - Security Policy Enforcement in virtualized Environments
  - Hardware Acceleration in SDN/NFV
  - Formal Security Policy Verification
Research Questions

- What **Security Properties** can be achieved in Virtualized Network Environments?

- Are there fundamental **Limitations**?

- What are the **Chances** introduced by Network Virtualization?
Introduction & Research

- Edwin Cordeiro
- Chair of Network Architectures and Services

- Real-time Automated Traffic Engineering
- Congestion Detection in the Internet
- Software Defined Networks
- Interface to the Routing System (I2RS)
Open Questions

- Impact of automated traffic engineering in current network protocols
- Detecting congestion without a probe at the destination
  - Parameters and thresholds to detect congestion in the Internet
  - Building a "ground truth" propagation time for a new destination
  - Low bandwidth utilization
- I2RS implementation
  - Understanding Quagga architecture to properly add I2RS to it
  - Analysis of YANG data models proposed by the working group
Research

- Linux nftables network vm (similar to bpf)
  - provides 'building blocks' for packet/flow classification
  - frontend tool (nft) to allow adding filters, traffic accounting, policing, ...
- extend it to provide programmable network stack/forwarding plane
- Linux network stack parallelization & scalability
  - RCU-ification (lockless data structures)
  - percpu data only when needed
  - be cache friendly
Open Questions

- Legacy and deployment issues
  - ECN
  - UDP (encap) everywhere, implications?
- consider implementation issues during protocol design
- improve research vs. standardization vs. deployment
  - IKE, Datacenter TCP, ...
Research

Software Defined Radio
- Full stack research & development
- PHY, MAC, Security, IP and upper layers

TCP Traffic Optimizer
- Live analysis on flow basis
- Duplicate checks, reordering and SACK optimizations
- Keepalive packets to keep connections alive

Mobile AdHoc Network Protocol
- Similar to OLSR
- Implemented in MAC layer, bit packed
- Metric extensions
- Dynamic Intervals based on network characteristics

Decentralized Time Management Protocol
- For Mobile AdHoc Networks, no preconfigured master node supporting network merge and splitting
- Accuracy of <20 µs
- Path delay detection and compensation up to 200 nmi

Active Queue Management
Packet Classification Engine (similar to BPF)

Hagen Paul Pfeifer
hagen@jauu.net
Rohde & Schwarz, Munich
Secure Communications
Open Questions

Multilink Routing Protocol for MANETs

- Interior MANET protocols work quite well!
- How to connect several (e.g. hundreds) MANETs?
  Networks of MANETs (“BGP for MANETs”)

  - Dynamic environment, IP prefixes change permanently, terminals come and go (no static BGP setup)
  - Load-sharing is a requirement – policy-based routing

Reliable Multicast Pub/Sub Framework with Policy-based Congestion Control/Transmission Mechanisms

  - Think of MQTT/ZEROMQ for larger, multi-hop networks with fluctuating channel characteristics
  - Reliable characteristics required – via retransmission
  - Dynamic switching to TCP when only one subscriber is available
Current Research Interests

• Network Measurements
• Network Troubleshooting
• Robust Internet Access
Open Question(s)
Research

- **Work Experience** 🇩🇪 🇺🇸 🇬🇧 🇫🇮
  - 2016: Postdoc at TU Munich, Jörg Ott
  - 2007~2016: Postdoc, PhD, Project researcher at Univ. Helsinki
  - 2014 at Columbia University, Henning Schulzrinne, New York, USA
  - 2013 at Cambridge University, Jon Crowcroft, Cambridge, UK
  - 2012 at Deutsche Telekom Labs, Ben Hui, Berlin, Germany

- Mobile offloading, IoT security and privacy
IoT Security... as a Service?

- Securebox project
  - ACM CoNEXT CAN ’16

- Does it work?

- How to enable it in a cost-efficient way?
  - Implementation and Experiment
  - Observations and Lessons

- Is this actually a problem?
Dirk Kutscher

• CTO for Virtual Network Engine at Huawei German Research Center
• Platforms, architectures and applications for programmable networks
• Cloudifying telco and enterprise networks
• Evolving the Internet from circuits towards a platform for data access and dynamic computation
• IRTF ICNRG
Topics of Interest

• Performance in the presence of heterogeneity and dynamic network conditions

• Rethinking collaboration of apps, transport and forwarding

• New forwarding abstractions and SDN control for that

• Enabling dynamic computation in the network securely

• Use cases: IoT, blending VoD and live streaming
Mirja Kühlewind

Post-Doc at ETH Zurich Networked Systems Group (NSG)
IETF transport Area Director & IRTF maprg co-chair

Work area(s): transport protocols, Internet measurement, middlebox cooperation, congestion control/ECN, low latency support

EU-ICT MAMI Project (Jan’16 - Jul’18): https://mami-project.eu/
„Measurement and Architecture for a Middleboxed Internet“
  • Large-Scale measurement of middlebox impairments: how bad is it?
  • PATH*spider: https://pathspider.net/
  • Path Transparency Observatory (available end of 2016)
  • Path layer for transport-independent signaling & state management
    • Middlebox Cooperation Protocol (MCP)
    • Flexible Transport Layer (FTL): path selection and encryption
Open questions

• How to enable deployment of new (transport) protocols?

• How to select the right transport service (e.g. congestion control and reliability) for an application and for a certain path?

• How to enable ubiquitous encryption (incl. transport) while keeping the network manageable?

• How to share crypto context between different layers (over certain time frames)?

• How to provide better in-band measurement/monitoring facilities e.g. for network trouble-shooting?
Flexible, dynamic and resource-efficient internetworking

5G mobile networks for reliable, energy efficient and low latency machine-to-machine communication

Techno economic analysis & resilient network planning

Benefits
- new services
- Open Access
- FMC

Cost
- OPEX -service prov.
- energy
- CAPEX -infrastruct.
TUM LKN: Wolfgang Kellerer

Flexibility as a Network Design Guideline

Research questions

- How to cope with the emerging network dynamics?
- How to design a network for flexibility?
- What is the role of virtualization and SDN?
- How can we use “flexibility” as a measure to compare different system designs?

POSTER and TALK later today
TUM LKN: Raphael Durner

Network Security with NFV and SDN

**Scenario:**
- SDN and NFV in Campus and Business Networks
- Firewall moves from the edge of the network to the inside → virtualized firewall everywhere

**Known:**
- Network-Functions can be run virtualized in a local or remote cloud
- SDN changes connectivity approach from „allow-first-restrict-later“ to „restrict-first-allow-later“

*Figure: SDN with VNFs on the example of Firewalls. The firewall could be NFV-only, SDN-only or a combined approach*
Network Security with NFV and SDN

Research questions:
- How to combine SDN and NFV efficiently
  - SDN-only NFV
  - Plain NFV with SDN for load-balancing
  - Hybrid NFV combines both
- What new attack vectors result from SDN
  - e.g. separation of Control and Data Plane can make a black hole network attack possible

POSTER The Cost of Security in the SDN Control Plane:
- Cost of employing TLS with OpenFlow
- Support of TLS in the OpenFlow
Brian Trammell

• Senior Researcher (80%)
  Networked Systems Group, ETH Zürich
• Architecture Evangelist (20%)
  Network Security Group, ETH Zürich

• Measurement of *Internet path transparency* and deployability of new (layer 4+) protocols (H2020 MAMI).
• Transport stack re-architecture: new interfaces for *explicitly multipath* connectivity and explicit cooperation with devices on path (H2020 MAMI).
• Future infrastructures for Internet naming and incremental deployment of an FIA (scion-architecture.net).
Open question

- Is there still room for “Internet architecture” as a practice: how can we transition research-derived technologies on to the Internet on purpose?

- This is as much a question of economics and the accidents of history as the fundamental properties of the technologies themselves.
Nokia Bell Labs Munich
End to End Mobile Network Solutions Research

• Dr. Marco Hoffmann
  – Technology Manager for Softwarization
  – Project Manager of Celtic+ SENDATE

• Dr. Rastin Pries
  – Senior Research Engineer Mobile Network 5G

• Research topics
  – 5G architecture
  – Network slicing
  – Network Function Virtualization and placement
  – Distributed Cloud
  – Security
Introduction & Research

- Daniel Raumer
- Chair of Network Architectures and Services
- Testbed for performance measurements
- Software-based network components
Open Questions

- Improving the scientific workflow within the Baltikum testbed; including *automation, documentation, ease of use, reproducibility, quality*

- Performance measurements within the testbed
- Combination of models and measurements
Introduction & Research

- Paul Emmerich
- Chair of Network Architectures and Services
- MoonGen packet generator
- Reproducible network experiments
- Packet processing and forwarding in software
Talk to me about...

- Do you use a packet generator?
  - Which one?
  - For what?
  - How do you use it?
  - Which features do you care about?
  - What can be improved?

- Software packet processing systems that I’ve worked on
  - For example: high-speed packet capturing at > 100 Gbit/s
  - See poster for details
Vaibhav Bajpai
PhD / Postdoctoral Researcher — advised by Prof. Dr. Jürgen Schönwälder
[2017 -]
Postdoctoral Researcher — advised by Prof. Dr. Jörg Ott

Research

- Performance Measurement Platforms
  [COMST 2015] [CCR 2015] [IM 2017] [ietf-lmap-yang,-restconf]

- Measuring IPv6 Performance
  [PAM 2015] [NETWORKING 2015] [ANRW 2016] [CNSM 2016]

- Dissecting Last-mile Latency Characteristics

- NetFlow / IPFIX Flow Analysis
  [TNSM 2017] [IM 2013]
Open Questions

- What can DNSSEC (~3%) learn from IPv6 (~15%) adoption?
- How can we get corporate networks to adopt IPv6?
- Can we simply leave Internet innovation to large CDN players?
Introduction & Research

- Dr. Matthias Wachs
- Chair of Network Architectures and Services

- Secure and privacy-preserving communication: Project “TUM Secure E-Mail and User Certification”
- Impact of emerging communication services: Security & privacy of mobile platforms & messaging
- Decentralization and adaptable architectures: Improving network security & resilience through adaption
- Future Architectures & communication services
Open Questions

• What is today’s state of networked services?
  • How can we evaluate resilience and security in the wild?
  • How can we improve security and resilience?
  • How do service paradigms change? What is the impact?

• How can we evolve today’s systems?
  • How can we achieve usable security by design?
  • What building blocks, protocols and systems do we need?

• What are requirements for future (communication) services?

• How can we design reliable services and networks?
  • What are requirements? Cooperation? Adaption?
  • What is a design for resilient, adaptive, cooperative systems and services?
Jörg Ott

• TUM, CS, Chair of Connected Mobility

• Working on
  – Mobile connectivity and service platforms
    (Living Lab Connected Mobility)
  – Cloud transport and service infrastructure (EC H2020 SSICLOPS)
  – Internet for All: architectures and services (EC H2020 RIFE)
  – End-to-end measurements (EC FP7 ITN METRICS)
  – WebRTC real-time measurements (callstats.io)

• Meta themes
  – Network architecture (DTN, ICN, …)
  – IP multimedia transport
  – Measurements; mobility and user behavior modeling; QoE
  – Connecting (mobile) things and mobile users and maintaining privacy
Some questions

• Future Internet transport

• Lessons from ICN and DTN for Internet protocols

• New architectures and deployability

• Sensible modes of operation for MIR³
Christian Prehofer

Working on
• Adaptive Cyber-physical Systems
  • Security & safety
• Open, secure platforms & trusted apps
• Internet of Things

Things to discuss
• System Security and Internet of Things
• Security by design
• Runtime Adaptation & Safety
Dr. Lars Eggert
Technical Director, Networking, NetApp

**History**
- 2011– NetApp
- 2007–11 Nokia
- 2003–07 NEC
- 2003 Ph.D., USC/ISI

**Academic**
- SIGCOMM, boards, 90+ PCs

**IETF**
- 2016– QUIC WG chair
- 2011–17 IRTF chair
- 2006–11 Transport AD
Data Plane
TUM LKN: Dr. Péter Babarczi
Post-Doctoral Research Associate

MTA-BME Future Internet Research Group
Budapest University of Technology and Economics, Hungary

Humboldt Post-Doctoral Research Fellowship @ TUM LKN (from 2017)

- Scalable and efficient multipath Internet routing
  - Independent spanning trees
  - End-host based path selection

- Instantaneous failure recovery in transport networks
  - Network coding/diversity coding
  - No flow rerouting or packet retransmission upon failure

- All-optical failure localization with supervisory lightpaths
  - Support fast protection switching

- Alert-based reconfiguration of virtual SDN networks
LKN: Andreas Blenk

Topic: Analysis, Modeling, and Optimization for Dynamic and Software-Defined Virtual Networks

Research Scenario
- Combine Network Virtualization (NV) + Software Defined Networking (SDN)
- Provide control to virtual network tenants
- Dynamically changing virtual network environments

Research Goals
- Models for Optimization of Data/Control Plane Resources in Virtual (SDN) Environments
- Design of Adaptive Network Virtualization Layer (SDN Network Hypervisors)

©Andreas Blenk@LKN TUM – andreas.blenk@tum.de
Methodologies & Results

Methodologies Applied
- Simulation-based Analysis [1,3,4]
- Linear/Mixed Integer Programming [1,3]
- Network Analytics (Machine Learning) [4]
- Neural Networks for System Optimization [4]
- Graph Features-based Analysis [4]
- Network Measurements [2]
- Proof of Concept Implementation [2]

Feedback on Results?
- Analyze trade offs: reconfigurations vs network utilization [1]
- SDN-based network virtualization architecture design [2]
- Models for analyzing SDN network hypervisors [3]
- POSTER: Neural Network-based admission control for Virtual Network Embedding [4]

Observations:
- Number of virtual networks impact latency
- Trade-offs among strategies

Model Latency Objectives
- Maximum
- Average
- Average Maximum
- Maximum Average

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Georg Carle: Research Interests

Topics
Network measurements
• Packet processing performance
• Internet-wide properties
Network architecture
• Network security and privacy
• Network resilience
• Network virtualization
• Low-latency communication

Methods
Automated performance measurements in testbed
Large-scale distributed measurements
Formal methods for network security functions
Topics for Discussions

SDN and Virtualisation
• Can we predict how SDN will be deployed?
• What are relevant research challenges for SDN?
• What are relevant research challenges for NFV?
• Are we satisfied with the security properties of SDN?

High performance packet processing
• Which limits exist for software packet processing?
• Which role do reprogrammable hardware components / FPGAs have in the network stack?

Reproducibility
• What are suitable reference scenarios?
• Are we aware network experiments that are hard to reproduce?

What is the future relevance of the following Hot Internet Topics?
• Information-Centric Networking; Delay-Tolerant Networking; Resource Public Key Infrastructure (RPKI); ...
Device-to-Device Communication

**Scenario:**
- Direct communication in cellular networks
- Allow dynamic frequency reuse

**Known:**
- D2D Produces 3 types of gains:
  - Proximity-gain, hop-gain and reuse-gain
- Resource reuse produces complex interference situations

**Active Research Questions:**
- How to measure the „gains“ of D2D?
- How much service penetration is needed for D2D to happen?
- How to precondition links for frequency reuse?
POSTER: Operation and Control of Device-to-Device Communication

Featuring:

- The ability of Sum-Rate to capture network “quality“
- A saturation effect on D2D-link density
- Insights on Interference Management basics

Open to discuss:

- How far can we push SD“X“ into wireless domain?
TUM LKN: Alberto Martínez Alba

Flexibility in Software Defined and Virtualized Wireless Networks

Research keynotes:

- Measuring flexibility of wireless networks
- Focus on mobile wireless networks enhanced by:
  - Software Defined Networks
  - Network Virtualization
  - 5G technologies

*Figure:* Example of a combination of SDN, NV and other 5G proposals that could enhance the flexibility of mobile networks
Flexibility in Software Defined and Virtualized Wireless Networks

Open questions:

- How wireless networks can be virtualized and/or software defined
- How to measure flexibility of wireless networks
- How 5G proposals can improve flexibility
  - e.g. Coordinated MultiPoint, massive MIMO, D2D, etc.
- Derive guidelines to design flexible wireless networks
TUM LKN: Nemanja Đerić

Design and Analysis of Function Placement Strategies for Future Mobile Networks

Main Focus:
- Future Mobile Networks (5G)
- Challenges of Distributed Cloud Architecture
- Software Defined Networking (SDN) & Network Functions Virtualization (NFV)
TUM LKN: Nemanja Đerić

Design and Analysis of Function Placement Strategies for Future Mobile Networks

Research Topics:
- Flexible Network Functions Placement
- Network Virtualization
- Network Slicing
- Data Center Placement
- Distributed Cloud Architecture
Introduction & Research

- Heiko Niedermayer
- Chair of Network Architectures and Services
- Network Security
- Resilience
- Modeling and Data Analysis
Open Questions

- Do multipath methods make sense on Internet-wide level due to hidden backup links?
- Do we want certificate transparency or other forms of enhanced certificate protection in cases of client certificates?
- Can we model and predict performance and robustness of cloud services and cloud communication?
Introduction & Research

- Minoo Rouhi
- Chair of Network Architectures and Services
- Large-scale Internet Measurements
- IPv4/IPv6 Sibling Validation
Open Questions

- IP sibling validation and sibling-based path tracing
  - Reducing measurement efforts
  - Automation of sibling acquisition
  - Smart learning of discerning metrics

- Detecting and analyzing network topologies
  - Reproducing network topologies in a virtualized testbed
  - Analysis of network bottlenecks
Introduction & Research

- Sebastian Gallenmüller
- Chair of Network Architectures and Services

- Measurements of systems for packet processing
- Packet processing in software
- Reproducible network experiments
Open Questions

- Measuring and modeling of a networked cyber-physical system (nCPS)
- Building a testbed for reproducible wireless measurements
  - Integrate the wireless hardware into the Baltikum testbed
  - Integrate precise energy measurement setup
- Set up a control system as an example for a nCPS
  - Software simulation of a two way inverted pendulum (*Segway*)
  - Prepare for measurements of a hardware nCPS
Introduction & Research

• Johannes Naab
• Chair of Network Architectures and Services

• DNS
• Flow (as in IPFIX) Monitoring
• Anomaly Detection, Intrusion Detection Systems

• Poster: DNS Research
• Poster: AutoMon
  Automatisiertes Performance-Monitoring
Open Questions

• Large Scale DNS monitoring/scanning
  • Only for the sake of DNS? What are other use cases?
  • Public/reliable domain name sources other than Alexa, Zone files, certificates, and reverse DNS?

• (Distributed) Denial of Service Attacks
  • Defenses beyond centralization? Which mitigations are possible without moving behind content delivery networks and “security” providers like Cloudflare?